TECHNICAL REPORT 3037
September 2016

Baleen Whale Responses to a High-Frequency Active Pinger: Implications for Upper Frequency Hearing Limits

Elizabeth Henderson

Approved for public release.

SSC Pacific
San Diego, CA 92152-5001

SSC SAN DIEGO
San Diego, California 92152-5001

K. J. Rothenhaus, CAPT, USN
Commanding Officer

C. A. Keeney
Executive Director

ADMINISTRATIVE INFORMATION

The work described in this report was performed by the Marine Mammal Scientific & Vet Support Branch (Code 71510) of the Biosciences Division (Code 71500), Space and Naval Warfare Systems Center Pacific (SSC Pacific), San Diego, CA.

Released under authority of
M. J. Xitco, Head
Biosciences Division

SB

EXECUTIVE SUMMARY

To test the possibility of using high-frequency pinger tags to track baleen whales on Navy instrumented ranges, three blue (*Balaenoptera musculus*) and one humpback (*Megaptera novaeangliaea*) whales were exposed to two high-frequency pingers from a small boat. The pinger frequencies were 37 and 45 kHz, with source levels of 174 and 163 dB re 1 μPa at 1 m respectively, and repetition rates of one ping per second. Estimated received levels varied between 106 and 134 dB re 1 μPa, with a closest approach distance of 100 m. The whales were monitored for at least an hour prior to the exposure to establish their behavioral state, diving and surface durations, and headings, as well as to acclimate them to the presence of the boat. Two of the blue whales were deep foraging during the exposure, while the third blue whale and the humpback whale were traveling with intermittent bouts of possible surfacing feeding or searching for prey. Each exposure lasted approximately 30–40 minutes while the behavior of the whales continued to be monitored, and the whales were observed for an additional two to three surfacing intervals post-exposure to ensure that their behavior continued as normal. None of the blue whales demonstrated any behavioral response, and continued their normal surface behavior, dive patterns, and dive durations. The humpback whale continued its prior travel heading and speed during the pinger exposure but reduced its dive interval times; however, it had been traveling with a foraging mixed species aggregation of birds and dolphins earlier in the day and rejoined this aggregation at this time and the change in behavior was similar to what had been observed prior. Therefore, it is inconclusive whether the humpback whale responded to the pinger or changed its behavior relative to the other animals in the area, although based on observations, the latter appears more likely. These data begin to provide information on the upper frequency limits of baleen whale hearing. Additional testing during different behavioral states and using different frequencies and source levels will contribute further knowledge to this topic.

CONTENTS

Figures

Tables

1. INTRODUCTION

While many advancements have been made in the last few decades to measure the hearing capabilities of many marine mammals (e.g., Babushina, Zaslavsky, and Yurkevich, 1991; Brill, Moore, and Dankiewicz, 2001; Finneran, Houser, Blasko, Hicks, Hudson, and Osborn, 2008; Gaspard, Bauer, Reep, Dziuk, Cardwell, Read, and Mann, 2012; Ghoul and Reichmuth, 2013; Greenhow, Brodsky, Lingenfelser, and Mann, 2014), the hearing capabilities of large baleen whales are still poorly understood. Theoretical audiograms have been constructed using models (Houser, Helweg and Moore, 2001; Ketten, 2012; Cranford and Krysl, 2015), and this information has been synthesized to create a hypothetical audiogram used by the U.S. Navy to estimate behavioral responses to various noise sources (Finneran, 2016; Figure 1). This audiogram estimates a very steep increase in hearing threshold above 20 kHz, such that over 20 kHz a sound would have to be at least 20 dB louder to be detected at the same level as a sound between one and ten kHz, and by 50 kHz a sound may no longer even be heard. However, no hearing tests have been successfully conducted on baleen whales, either through psychophysical auditory evoked potential (AEP) or auditory brainstem response (ABR) testing or through behavioral testing. Behavioral hearing tests in captive marine mammals have been a very successful method of assessing hearing capabilities (Houser, Finneran, Carder, Ridgway, and Moore, 2004; Yuen, Nachtigall, Breese, and Supin, 2005; Schlundt, Finneran, Branstetter, Dear, Houser, and Hernandez, 2008) as these animals are trained to respond when they hear a stimulus. This method is more difficult to use with wild marine mammals, as there are often other stimuli present in addition to the sound of interest (e.g., boats, equipment in the water, etc.) making it difficult to distinguish between a reaction to the sound and a reaction to other stimuli. In addition, animals may not respond at all, or may demonstrate very subtle responses to sounds just above their hearing threshold, which may mislead the results as to the true frequencies an animal may detect versus those they actually respond to in a manner observable by researchers. However, behavioral methods are currently the best available tool to begin assessing the upper frequency hearing capabilities of baleen whales.

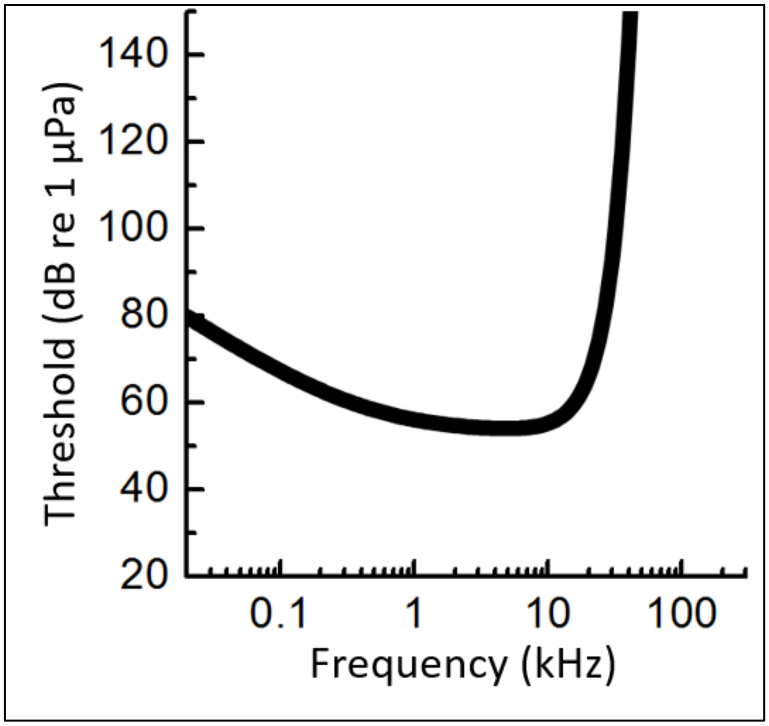

Figure 1. Composite baleen whale audiogram developed by Finneran (2016).

Using multi-hydrophone arrays and time difference of arrival (TDOA) methods, vocalizing marine mammals can be localized and successive vocalizations can be tracked over time. When enough hydrophones exist over a large spatial extent, animals can be tracked for long periods of time and over broad distances as long as they continue to vocalize, as has been done for humpback whales (*Megaptera novaeangliae*), Bryde's whales (*Balaenoptera brydei*), and minke whales (*Balaenoptera acutorostrata*) at the Pacific Missile Range Facility (PMRF) near the island of Kauai in the Hawaiian archipelago (Helble, Ierley, Gerald, and Martin, 2015; Martin, Martin, Matsuyama, and Henderson 2015; Helble, Martin, Ierley, and Henderson, 2016). However, when an animal ceases to vocalize they can no longer be tracked, and assumptions must be made when a new vocalization bout begins as to whether or not it is the same or a different animal. In addition, little information is known on how long individual animals of various species may remain in a localized region, such as on or near a Navy range, or on the calling rates of many baleen whale species. These assumptions and pieces of missing information lead to density estimations undercounting the number of animals in the area, potentially by a third or more. A high-frequency pinger, beyond the range of high-frequency hearing capabilities of baleen whales but within the 96-kHz sampling rate (48 kHz effective sampling bandwidth) of Navy hydrophones, could be attached to baleen whales to track them on Navy ranges. This would preclude the need for the animal to be vocalizing, and could capture a broader demographic of animals; for example, only male humpback whales sing, so currently females and calves are not being acoustically localized. The amount of time individual animals remain in an area, or the frequency at which they return, could be estimated, as could the amount of time an animal of a given demographic (e.g., adult, juvenile, male, female) vocalizes. All of this information would be valuable in informing density estimations of animals that live too far offshore for visual methods to be implemented. In addition, these pinger tags could be used to track animals during and after Navy training events that use a number of vessels and mid-frequency active sonar (MFAS) in order to observe whether behavioral reactions occur beyond a cessation of vocalizations, and to capture the

severity of those responses. However, before developing such a pinger tag, the upper frequency hearing capabilities of potential baleen whale targets needs to be tested to ensure that they cannot hear the pinger signal and that it does not disrupt their normal behavior, nor does it disrupt the behavior of other species in the area that may be able to detect the signal, including delphinid and pinniped species.

The goals of this study were to assess the potential for behavioral responses by baleen whales to pingers with different frequencies and source levels. By controlling the additional external variables as much as possible during a controlled exposure experiment, the responses of focal whales could be monitored and therefore could be largely attributable to the sounds from the pinger.

2. METHODS

Humpback whales were the preferential focal species, followed by blue (*Balaenoptera musculus*) and fin (*Balaenoptera physalus*) whales. Other marine mammals that could have been present and exposed to the playback include bottlenose dolphins (*Tursiops truncatus*), Pacific white-sided dolphins (*Lagenorhynchus obliquidens*), long- and short-beaked common dolphins (*Delphinus capensis* and *D. delphis*), northern right whale dolphins (*Lissodelphis borealis*), and California sea lions (*Zalophus californianus*). Lone animals were preferentially approached to keep the playback exposures to a minimum, and to allow close observation of the focal animal(s). However, the area within 1 km (assuming 60 dB of signal attenuation) around the vessel was continually monitored for additional animals, which if sighted were also kept under behavioral observation.

Two pingers were used to conduct the behavioral response testing. The first had a nominal source level (SL = re 1 μPa at 1 m) of 163 dB at a frequency of 45 kHz, while the second pinger had a frequency of 37 kHz with an SL of 174 dB. Both pingers had a ping duration of 5–10 ms, and a pulse repetition rate of 1 ping per second (Table 1). These pingers were tested in San Diego Bay to assess their acoustic characteristics. Using spherical spreading, a 160-dB source level (SL) signal would attenuate to less than 100 dB within 2 km, while a 174-dB signal would attenuate to below 100 dB within 6 km.

Table 1. Signal characteristics of two pingers and received levels at three distances. Source and received levels are given in dB re 1 μPa.

Frequency (kHz)	Nominal Source Level	Pulse Length (ms)	Distance (ft)	dB p2p	dB peak	dB rms	SEL
37	174	5	9	178.0	172.0	168.3	145.0
37	174	5	35	164.0	158.1	153.1	131.3
37	174	5	98	162.3	156.3	147.9	129.9
45	163	10	9	163.4	157.1	151.1	133.7
45	163	10	35	151.3	144.9	124.5	121.2
45	163	10	98	149.9	143.4	116.8	115.9

2.1 CLOSE APPROACHES AND PINGER DEPLOYMENT

Once a focal whale was located, it was approached and followed at a distance greater than 100 m. By keeping a distance of at least 100 m (assuming 40 dB of signal attenuation), the impact on the behavior of the focal animal due to the presence of the vessel was minimized. During this initial approach phase, the following information was gathered: (1) the focal whale's baseline behavioral state, (2) the presence of other whales or marine mammals in the area, (3) any possible interactions of the focal whale with any other animals, and (4) any response of the focal whale to the vessel itself. This initial observation phase lasted for a minimum of 1 hour. The area within 1 km of the vessel was also continuously monitored for other marine mammals moving into or out of the area. This initial monitoring continued until the whale's behavior had been established and there did not appear to be any impact to their behavior by the presence of the vessel. At this time the pingers were deployed.

The pingers were deployed 1–2 m below the surface of the water using a rigid pole. If possible, the vessel would remain stationary or move at a speed below 2–3 knots, and observers monitored the initial and subsequent behavior of the animal after deployment. A Reason 4032 hydrophone

(http://www.teledyne-reson.com/product/tc-4032) could also be deployed at this time to record any possible acoustic responses if the vessel was stationary with the engines off. The hydrophone was recorded using a Tascam HD-P2 field recorder with a sampling bandwidth of 96 kHz at 16 bits (http://tascam.com/product/hd-p2/) and a VP-1000 pre-amplifier with a high-pass filter at 10 Hz. If no response was detected, the vessel would very slowly track the whale, remaining at a distance of >100 m. Responses by the focal animals could include anything from subtle behaviors such as tonal blows, tail flicks or swishes, changes in dive duration or respiration rate, or changes in travel direction up to more obvious responses such as surface activity or clear avoidance of the vessel/pinger. If there continued to be no response over several surfacing intervals, the vessel slowly approached the animal with the pinger in the water. This slow approach created a ramp-up effect, allowing the received level of the pinger to be slowly increased while monitoring for a response. The approach was conducted slowly and cautiously, so as not to introduce a spurious response to the vessel rather than the pinger. Observers continued to monitor both the focal animal and any other animals in the area, to ensure there was no response in any animals within hearing range of the pinger and visual range of the vessel. Finally, the pinger was removed and the whale was observed for a few more surfacing intervals to ensure that behavior continued as normal. This effort lasted for several hours for each focal whale, as long as the focal whale was within sight and no response was observed.

2.2 DATA RECORDING

The timing, location, and type of every event was recorded during this playback experiment. Events included initial sighting and identification of focal species; initial behavioral monitoring with location, distance and behavior updated every surfacing interval; any sightings of other marine mammals and their distance and behavior, updated every 5 minutes; the initial deployment of the pinger and subsequent behaviors by the focal animal(s); the deployment of a hydrophone; behavior and distance updates of the focal animal(s) every surfacing interval during the slow close approach; and the final behavioral state and distance of the focal animal(s) or any animals in the area as the pinger was removed from the water. In addition, environmental data was recorded every hour or as conditions changed and upon locating a focal animal. These data included the sea state, swell height, wind speed and direction, cloud cover and water depth.

2.3 RESULTS

Surveys were conducted over 5 days in June 2016 in nearshore waters out to 15 km off La Jolla, California. The study area extended north to San Clemente, and south to the EEZ border of Mexico (Figure 2). This work was conducted using a 5.9 m rigid-hulled inflatable boat traveling between 10 and 15 knots, with three to four observers scanning in all directions for focal whales. A summary of the species sighted is given in Table 2; of the six humpback and five blue whales observed on 3 of the 5 days, pingers were deployed near one humpback and three blue whales (Figure 2).

Table 2. Numbers of each species sighted and exposed to pinger playback.

Species	# Sighted	# Playback
Humpback whale	6	1
Blue whale	5	3
Common dolphins	3100	20
Bottlenose dolphins	10	0

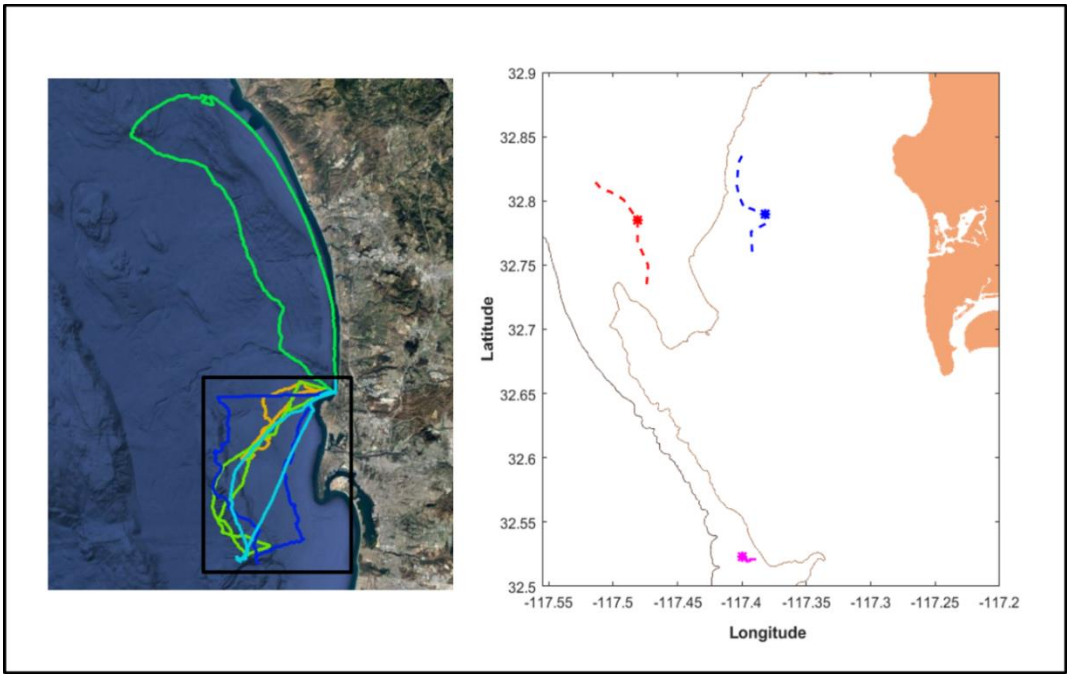

Figure 2. Tracks showing 5 days of survey effort off San Diego, CA (left), and tracks of the three pinger playback experiments (right). The blue track is the humpback whale, the pink track shows the two deep foraging blue whales, and the red track is the traveling blue whale. The asterisks represent the location of the initial pinger deployments. The dark lines indicate the 1000-m depth contours.

2.3.1 Playback 1: Humpback Whale and Common Dolphins

A humpback whale was encountered with a large group of common dolphins and birds, all of which were traveling south/southeast, with the whale typically less than 500 m behind the other species. This whale had short, regular dive times of 2.5–3.5 minutes, and initially traveled steadily between 2 and 5 knots heading south/southeast. After an hour of observation and tracking the whale, other species had moved south/southeast beyond 500 m, so we prepared to deploy the first pinger. However, the whale then joined another mixed species feeding aggregation and began circling/ milling, which continued for 10–15 minutes, and then the whale resumed its south/southeast travel behavior. The other species had again begun moving out of the area, so the pinger (45 kHz, 163 dB re 1 μPa at 1 m) was deployed with the boat parallel to the whale and ~100 m away. At this time, the received level at the focal animal should have been approximately 123 dB re 1 μPa, based on simple spherical spreading. The whale completed two additional surfacings with 2.5- to 3.5-minute dives, and then dove; the dolphins (>1 km away) continued traveling east/southeast away from the boat. After a 2.6-minute dive, the animal surfaced on the opposite side of the boat, having shifted its travel direction slightly to the south. The animal continued traveling southwest, varying its heading between 210 and 180 degrees and its speed between 2 and 4 knots, with the same surfacing and dive behavior as previously observed, although slightly shorter dive times (< 2 minutes). Several small groups of common dolphins entered the area; most remained outside of 100 m; however, at least one animal passed right by the boat within 10 m of the pinger. As more dolphins and birds entered the general area (within 2 km), the whale began to change its heading more frequently, and altered its dive behavior to single surfacings, followed by fluke up dives, with ~ 1-minute dive times. During this time, small groups of dolphins (~50 animals) came within 100 m, with four to six dolphins bow-riding; all dolphins continued traveling north while we tracked the whale still generally traveling

south. More dolphins and birds continued to enter the area from all directions; three additional dolphins approached to bow-ride. The received levels for the bow-riding common dolphins likely ranged between 143 and 157 dB re 1 μPa. The whale finally turned east towards one mixed species aggregation and began circling. The pinger was pulled at that time, as there were too many dolphins approaching within 100 m and would be considered incidental exposures. There was no response to the pinger observed for any of the dolphins, and several approached the boat normally with some bow-riding while the pinger was deployed. There was no overt or obvious response (e.g., no surface activity, no clear avoidance) to the pinger by the whale; immediately after deployment, the whale continued normal surfacing and dive behavior. The whale did begin altering its heading and shortened its dive times, but this seemed to be in response to other animals in the area as described above, and no clear avoidance behavior was observed.

2.3.2 Playback 2: Blue Whales

A blue whale was encountered that continued circling in one area, with long dive times (12–14 minutes) and long surface intervals (12–16 blows), and so was likely deep foraging. The hydrophone was deployed, but no feeding calls or other blue whale vocalizations were recorded. A second blue whale was also in the area, and was also likely deep foraging with slightly shorter dive times. This whale was never approached, and our closest distance was at least 500 m, typically 700–1000 m. After an hour of observation, the pinger (45 kHz, 160 dB re 1 μPa SL) was deployed on the closer whale, at distances from 100–500 m, with estimated received levels of 106–120 dB re 1 μPa. The second whale likely never experienced a received level over 106 dB re 1 μPa. Neither whale demonstrated any kind of response throughout the 30-minute exposure, but continued the same dive intervals and number of respirations at the surface. There was also a group of common dolphins fast traveling away when we initially deployed the pinger, but they were already at least 1 km away and continued heading away so did not receive the playback exposure.

2.3.3 Playback 3: Blue Whales

A blue whale traveling northwest was encountered, with dive times varying between 6 and 10 minutes. It had a brief period of 1- to 2-minute dives and short surfacings and changed direction a few times—it appeared as though it might have either been surface feeding or assessing a patch to feed, but then continued on traveling NW. At that point the pinger (37 kHz, 174 dB re 1 μPa) was deployed twice, at distances of 100 and 150 m. There was no overt response in either case, and the whale continued the same general travel behavior, bearing, and surface behavior. As this was the pinger with the louder source level, the maximum received level was about 134 dB re 1 μPa. No other animals were observed in the area during this playback.

3. CONCLUSION

High-frequency acoustic pingers were successfully deployed near four baleen whales with no overt behavioral responses observed. Potential responses could have ranged from a startle response as the pinger was first put into the water, to pec-, fluke-, or head-slapping or other indications of disturbance, to a change in behavioral state or avoidance of the sound source. As none of these responses were observed, initial results indicate that these whales either did not hear the pinger, or that the received level was low enough not to cause any response. According to the composite audiogram developed by Finneran (2016), baleen whale hearing thresholds at 37 and 45 kHz are 50 to 80 dB re 1 μPa higher than the thresholds in the range of best hearing (1–10 kHz). Even using the more conservative weighting function developed by Finneran (2016) to estimate noise impacts indicates that levels of 106–134 dB re 1 μPa would be received by baleen whales at 91–122 dB re 1 μPa. At those levels, the pinger may have just been detectable, but if the thresholds from the audiogram are used, the sounds fall below ambient noise levels (26–84 dB re 1 μPa) and becomes undetectable by baleen whales. Since there was no visible response by any of the whales, it cannot be determined if the levels were actually below detection thresholds or if they were simply low enough not to cause a response, but results indicate that either way the pingers did not appear to disturb the animals.

However, this test was conducted on a very small number of individuals, with two species and different behavioral states represented. Blue whales in a behavioral response study of mid-frequency sonar that used much high source level tones well within the hearing range of the whales (3 kHz) demonstrated differential responses depending on their behavioral state. Deep foraging and non-feeding whales seemed to respond more readily and with a stronger avoidance response than shallow foraging whales (Goldbogen, Southall, DeRuiter, Calambokidis, Friedlaender, Hazen, Falcone, Schorr, Douglas, Moretti, Kyburg, McKenna and Tyack 2013; Friedlaender, Hazen, Goldbogen, Stimpert, Calambokidis and Southall 2016). Responses included a change in dive behavior, an orientation response, or avoidance, and these responses occurred at received levels between 130 and 160 dB re 1 μPa (Goldbogen et al., 2013), although some of these responses could only be detected using a tag. Note that the two whales in the present study that were in the more "sensitive" behavioral state of deep foraging did not appear to respond to the pinger, although levels were well below those of Goldbogen et al. (2013), and subtle behavioral changes of the animals when below the surface were not possible to detect, given our methods. In another behavioral response study, humpback whales responded to mid-frequency sonar (1–2 kHz) at received levels from 91 to 179 dB, but with most responses occurring only at levels above 140 dB re 1 μPa. Responses in this study included changes in orientation, avoidance, cessation of feeding. and a change in dive behavior, but there was no correlation between the occurrence of a response and a specific behavioral state (Sivle, Vadsheim, et al., 2015). The variability in the strength and type of responses across species and behavioral states in these studies emphasizes the caution needs to be taken in interpreting the results presented here. With such a low sample size, no definitive conclusions can be drawn on whether the whales detected the pingers at all.

These initial results support using the high-frequency pinger as a tracking device for baleen whales on Navy ranges, as it did not cause a response in observed whales. Before this occurs, additional behavioral response testing should be conducted to increase the sample size across species and behavioral states, and with increased received levels to ensure the animals still do not respond even at higher levels. Additional tests at higher levels will also provide data on the upper hearing limits of baleen whale hearing. If whales do not respond to increased received levels, even in behavioral states in which they seem to be more sensitive to noise (e.g., deep feeding in blue whales), then that

supports the steep increase in hearing thresholds at higher frequencies as estimated by Finneran (2016).

REFERENCES

Babushina, E. S., G. L. Zaslavsky, and L. I. Yurkevich. 1991. "Air and Underwater Hearing of the Northern Fur Seal: Audiograms and Auditory Frequency Discrimination," *Biofizika 36*(5):904–907.

Brill, R. L., P. W. B. Moore, and L. A. Dankiewicz. 2001. "Assessment of Dolphin (*Tursiops truncatus*) Auditory Sensitivity and Hearing Loss using Jawphones," *The Journal of the Acoustical Society of America 109*(4):1717–1722.

Cranford, T. W., and P. Krysl. (2015). "Fin Whale Sound Reception Mechanisms: Skull Vibration Enables Low-Frequency Hearing." *PloS One 10*(1)*:e0116222*.

Finneran, J. J. 2016. "Auditory Weighting Functions and TTS/PTS Exposure Functions for Marine Mammals Exposed to Underwater Noise." Technical Report 3026. Space and Naval Warfare Systems Center Pacific (SSC Pacific), San Diego, CA.

Finneran, J. J., D. S. Houser, D. Blasko, C. Hicks, J. Hudson, and M. Osborn. 2008. "Estimating Bottlenose Dolphin (*Tursiops truncatus*) Hearing Thresholds from Single and Multiple Simultaneous Auditory Evoked Potentials," *Journal of the Acoustical Society of America 123*(1):542–551.

Friedlaender, A. S., E. Hazen, J. Goldbogen, A. Stimpert, J. Calambokidis. and B. Southall. 2016. "Prey-mediated Behavioral Responses of Feeding Blue Whales in Controlled Sound Exposure Experiments" *Ecological Applications 26*(4):1075–1085. .

Gaspard, J. C., III, G. B. Bauer, R. L. Reep, K. Dziuk, A. Cardwell, L. Read, and D. A. Mann. 2012. "Audiogram and Auditory Critical Ratios of Two Florida Manatees (*Trichechus manatus latirostris*)." *Journal of Experimental Biology 215*:1442–1447.

Ghoul, A., and C. Reichmuth. 2013. "Psychophysical Studies of Hearing in Sea Otters (*Enhydra lutris*)," *The Journal of the Acoustical Society of America 134*(5):4210–4210.

Goldbogen, J. A., B. L. Southall, S. L. DeRuiter, J. Calambokidis, A. S. Friedlaender, E. L. Hazen, E. A. Falcone, G. S. Schorr, A. Douglas, D. J. Moretti, C. Kyburg, M. F. McKenna, and P. L. Tyack 2013. "Blue Whales Respond to Simulated Mid-frequency Military Sonar." *Proceedings of the Royal Society B: Biological Sciences 280*(1765).

Greenhow, D. R., M. C. Brodsky, R. G. Lingenfelser, and D. A. Mann. 2014. "Hearing Threshold Measurements of Five Stranded Short-finned Pilot Whales (*Globicephala macrorhynchus*)," *The Journal of the Acoustical Society of America 135*(1):531–536.

Helble, T. A., G. R. Ierley, L. Gerald, and S. W. Martin. 2015. "Automated Acoustic Localization and Call Association for Vocalizing Humpback Whales on the Navy's Pacific Missile Range Facility," *The Journal of the Acoustical Society of America 137*(1):11–21.

Helble, T. A., S. W. Martin, G. R. Ierley, and E. E. Henderson. 2016. "Swim Track Kinematics and Calling Behavior Attributed to Bryde's Whales on the Navy's Pacific Missile Range Facility," *The Journal of the Acoustical Society of America*: *10*.

Houser, D. S., J. J. Finneran, D. A. Carder, S. H. Ridgway, and P. W. B. Moore. 2004. "Relationship between Auditory Evoked Potential (AEP) and Behavioral Audiograms in Odontocete Cetaceans." *The Journal of the Acoustical Society of America 116*(4):2503(A).

Houser, D. S., D. A. Helweg, and P. W. B. Moore. 2001. "A Bandpass Filter-bank Model of Auditory Sensitivity in the Humpback Whale," *Aquatic Mammals 27*(2):82–91.

Ketten, D. R. 2012. "Modeling Minke Whale Hearing: Anatomical Substrates of Hearing." Joint Industry Programme on E&P Sound and Marine Life Programme Review Meeting II, Washington, DC.

Martin, S. W., C. R. Martin, B. M. Matsuyama, and E. E. Henderson, 2015. “Minke Whales (*Balaenoptera acutorostrata*) Respond to Navy Training,” *The Journal of the Acoustical Society of America 137*(5):2533–2541.

Schlundt, C. E., J. J. Finneran, B. K. Branstetter, R. L. Dear, D. S. Houser, and E. Hernandez. 2008. “Evoked Potential and Behavioral Hearing Thresholds in Nine Bottlenose Dolphins (*Tursiops truncatus*).” *The Journal of the Acoustical Society of America 123*:3506(A).

Sivle, L. D., P. H. Kvadsheim, C. Curé, S. Isojunno, P. J. Wensveen, F.-P. A. Lam, F. Visser, L. Kleivane, P. L. Tyack, and P. J. O. Miller, 2015. “Severity of Expert-Identified Behavioural Responses of Humpback Whale, Minke Whale and Northern Bottlenose Whale to Naval Sonar.” *Aquatic Mammals 41*(4):469–502.

Yuen, M. M. L., P. E. Nachtigall, M. Breese, and A. Y. Supin. 2005. “Behavioral and Auditory Evoked Potential Audiograms of a False Killer Whale (*Pseudorca crassidens*).” *The Journal of the Acoustical Society of America 118*(4):2688–2695.

REPORT DOCUMENTATION PAGE	Form Approved OMB No. 0704-01-0188

1. REPORT DATE *(DD-MM-YYYY)* September 2016	**2. REPORT TYPE** Final	**3. DATES COVERED** *(From - To)*
4. TITLE AND SUBTITLE Baleen Whale Responses to a High-Frequency Active Pinger: Implications for Upper Frequency Hearing Limits		**5a. CONTRACT NUMBER** **5b. GRANT NUMBER** **5c. PROGRAM ELEMENT NUMBER**
6. AUTHORS Elizabeth Henderson		**5d. PROJECT NUMBER** **5e. TASK NUMBER** **5f. WORK UNIT NUMBER**
7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES) SSC Pacific 53560 Hull Street San Diego, CA 92152–5001		**8. PERFORMING ORGANIZATION REPORT NUMBER** TR 3037
9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES) SSC Pacific Naval Innovative Science and Engineering (NISE) Program 53560 Hull Street San Diego, CA 92152–5001		**10. SPONSOR/MONITOR'S ACRONYM(S)** **11. SPONSOR/MONITOR'S REPORT NUMBER(S)**

12. DISTRIBUTION/AVAILABILITY STATEMENT

Approved for public release.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

To test the possibility of using high-frequency pinger tags to track baleen whales on Navy instrumented ranges, three blue (*Balaenoptera musculus*) and one humpback (*Megaptera novaeangliaea*) whales were exposed to two high-frequency pingers from a small boat. The pinger frequencies were 37 and 45 kHz, with source levels of 174 and 163 dB re 1 µPa at 1 m respectively, and repetition rates of one ping per second. Estimated received levels varied between 106 and 134 dB re 1 µPa, with a closest approach distance of 100 m. The whales were monitored for at least an hour prior to the exposure to establish their behavioral state, diving and surface durations, and headings, as well as to acclimate them to the presence of the boat. Two of the blue whales were deep foraging during the exposure, while the third blue whale and the humpback whale were traveling with intermittent bouts of possible surfacing feeding or searching for prey. Each exposure lasted approximately 30–40 minutes while the behavior of the whales continued to be monitored, and the whales were observed for an additional two to three surfacing intervals post-exposure to ensure that their behavior continued as normal. None of the blue whales demonstrated any behavioral response, and continued their normal surface behavior, dive patterns, and dive durations. The humpback whale continued its prior travel heading and speed during the pinger exposure but reduced its dive interval times; however, it had been traveling with a foraging mixed species aggregation of birds and dolphins earlier in the day and rejoined this aggregation at this time and the change in behavior was similar to what had been observed prior. Therefore, it is inconclusive whether the humpback whale responded to the pinger or changed its behavior relative to the other animals in the area, although based on observations, the latter appears more likely. These data begin to provide information on the upper frequency limits of baleen whale hearing. Additional testing during different behavioral states and using different frequencies and source levels will contribute further knowledge to this topic.

15. SUBJECT TERMS

high-frequency pinger tags; baleen whale hearing; tracking; Navy instrumental ranges; whale behavior

16. SECURITY CLASSIFICATION OF: a. REPORT	b. ABSTRACT	c. THIS PAGE	17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON / 19B. TELEPHONE NUMBER *(Include area code)*
U	U	U	U	18	Elizabeth Henderson 619-553-3507

Standard Form 298 (Rev. 8/98)
Prescribed by ANSI Std. Z39.18

INITIAL DISTRIBUTION

84300	Library	(1)
71510	E. Henderson	(1)

Defense Technical Information Center
Fort Belvoir, VA 22060–6218 (1)

Approved for public release.

SSC Pacific
San Diego, CA 92152-5001